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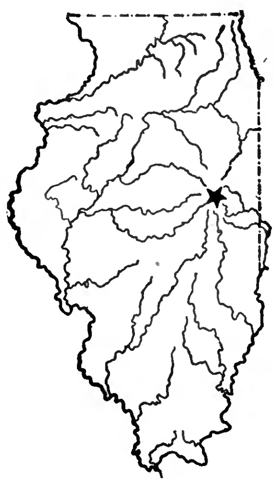
Agricultural Experiment Station.

BULLETIN NO. 99.

SOIL TREATMENT FOR THE LOWER ILLINOIS GLACIATION.

By CYRIL G. HOPKINS and J. E. READHIMER.



URBANA, ILLINOIS, MARCH, 1905.

Summary of Bulletin No. 99.

1. It is possible to adopt a profitable system of farming that will make the soils of southern Illinois permanently productive. Page 563

2. Chemical analyses show these soils to be quite deficient in nitrogen and organic matter, very deficient in phosphorus, only moderately well supplied with potassium, and markedly acid. Page 563

3. The effects of tile drainage upon these soils under certain conditions of season and treatment are very suggestive. Pages 565, 570, 575

4. Very beneficial results with legumes are obtained from the use of lime. Pages 573, 586

5. The results obtained from experiments strongly confirm the universal experience as to the very great value of farm manure upon this type of soil. Pages 569, 571, 589

6. By the use of liberal applications of lime and thorough inoculation with the proper nitrogen-gathering bacteria, clover can be grown on this type of soil with profit. Pages 571, 573, 587

7. While under certain conditions largely increased yields of oats and of corn have been obtained from the use of potassium, it is still questionable if commercial potassium can be used with profit. Pages 576, 588, 589

8. Phosphorus is the limiting element in these soils and must be used liberally in order to make them permanently productive. Pages 568, 577, 585, 592

9. A liberal use of legumes, to supply organic matter and nitrogen, must be an essential part of any practical and economical system that ever becomes successful in the permanent improvement of southern Illinois soils. Pages 585, 594

10. It is good farm practice to remove large quantities of plant food from the soil provided as large or larger amounts be returned when necessary. Page 594

11. This bulletin will be sent free of charge to any one interested in Illinois agriculture, upon request to E. Davenport, Director Agricultural Experiment Station, Urbana, Illinois; and if so requested, the name of the applicant will be placed upon the permanent mailing list of the Experiment Station, so that all subsequent bulletins will be sent to him as they are issued.

Recommendations **Page 594**

SOIL TREATMENT FOR THE LOWER ILLINOIS GLACIATION.

By CYRIL G. HOPKINS, Chief in Agronomy and Chemistry, and J. E. Readhimer, Superintendent of Soil Experiment Fields.

The chief reason for the thorough investigation of Illinois soils (now in progress) is to bring about methods of farming which shall at least permanently maintain the present high crop yields of our best soils and which shall increase the fertility of our poorer soils to their maximum profitable productive capacity. These investigations have been in progress only three years, but results are rapidly being obtained which are certainly of very great value to Illinois agriculture, and it is believed that these results should be promptly reported to the farmers and land owners of the state, even though final conclusions cannot as yet be drawn on all questions involved.

All of the most important soils are already being investigated, and the plans adopted and now in operation include a detail soil survey of the entire state and a thorough investigation of every type of soil found, by chemical and physical analysis, by exact pot culture experiments under controlled conditions, and so far as necessary by field experiments conducted in different sections of the state and under actual field conditions.

Among the most important results already obtained are those from the University soil experiment fields located in different parts of southern Illinois, especially on the common prairie soil in the Lower Illinois Glaciation, the oldest glaciated area in the state. This great area of agricultural land of depleted fertility includes the counties of Fayette, Effingham, Jasper, Marion, Clay, Richland, Washington, Jefferson, Wayne, Edwards, Perry, Franklin, and Hamilton, and parts of as many more surrounding counties. The principal type of soil in this area is a gray silt loam. It is not strictly a clay soil, although it is quite commonly spoken of as "clay," sometimes as "white clay." Silt consists of soil particles smaller than sand, and impalpable, but it is not sticky, plastic clay.

The chemical composition of this gray silt loam of the Lower Illinois Glaciation, as given on page 20 of Circular No. 68 (a copy of which can be obtained free of charge upon request to the Illinois Experiment Station, Urbana, Illinois), shows this soil to be only moderately well supplied with potassium, quite deficient in nitrogen and organic matter, exceedingly deficient in phosphorus, and markedly acid.

Four University soil experiment fields are located upon this type of soil:

(1) The Edgewood Field, one mile northwest of Edgewood, Effingham County, on the farm of Mr. Samuel Bartley.

(2) The Odin Field, one mile southwest of Odin, Marion County, on the farm of Col. N. B. Morrison.

(3) The DuBois Field, one and one-half miles northwest of DuBois (Bois Station), Washington County, on the farm of Mr. A. A. Hinkley.

(4) The Cutler Field, five miles northwest of Cutler, Perry County, on the farm of Mr. W. E. Braden.

The Edgewood field lies beside the Baltimore & Ohio Southwestern Railroad and the Odin field beside the Illinois Central Railroad. Either of these fields can be reached by a twenty minutes' walk from the station, along the railroad.

The DuBois field contains about three acres (aside from co-operative experiments), and the three other fields about fifteen acres each, including the exact experiment plots, division strips, and borders.

THE EDGEWOOD FIELD.

The Edgewood field consists of three parts, known as the West Field, the East Field, and the North Field.

THE WEST FIELD AT EDGEWOOD.—The west field contains two series of seven plots each, one series (plots 101 to 107), being not tile-drained, and the other series (plots 201 to 207), being tile-drained. Aside from the drainage, these two series of plots are treated and cropped alike. Experiments on this field were begun in 1896, the tile having been laid in the spring of that year. Three strings of tile were laid across all the plots in the 200 series, at a distance of 50 feet apart. Plot 101 was known to be somewhat better land than the average of the field, because of some surface wash which it once received from adjoining land. The original experiments were planned by Dean Davenport, and they included the work with tile drainage and also the green manure experiments with cow peas on plot 1 and buckwheat on plot 2, and the subsoiling on plot 7. After two or three years the management of the field was turned over to Professor Holden, who had the sodium nitrate applied in 1899. The authors of this bulletin are responsible for the management of the field since 1900, including the plan of soil treatment adopted in 1901 and applied for the 1902 crop.

This field was originally laid out in eight plots, with no division strips between the plots, and this arrangement was continued till the fall of 1901, when the number of plots was reduced to seven, with half-rod division strips between the plots. The yields reported in Table 1 are all given for the plot boundaries as now fixed, computations having

been made, where necessary, from the old plot yields. Thus, plot 1 is identical in both systems, no computations being required; but the present plot 2 consists of three-fourths of the former plot 2 and one-fourth of the former plot 3, and the yields are computed accordingly. A careful study of the two systems of plotting and of the actual and computed yields convinces us that no appreciable inaccuracy is introduced by this rearrangement, and it is a decided advantage, in that it provides for half-rod divisions between the plots, thus guarding against the treatment of one plot being allowed to affect the crop yields on an adjoining plot, and also making it possible to have the records of each plot continuous from the beginning, in 1896, up to the present time. Corn, oats, and legumes have been grown on this field as the principal crops during the past nine years, and hereafter a three-year rotation is to be practiced on the field as follows:

First year, corn.
Second year, oats.
Third year, legume.

On certain plots, in addition to the regular legume grown in the third year of the rotation, a legume catch crop is grown as often as possible, such as cow peas seeded in the corn when it is laid by. Lime (as ground limestone, unburned), phosphorus (as steamed bone meal), and potassium (as potassium chlorid or sulfate), and manure, are applied to plots as indicated. Table 1 shows the different kinds of treatment applied and the crop yields obtained from the west field at Edgewood for nine years, 1896 to 1904, inclusive.

During the nine years, Mr. Samuel Bartley has had immediate charge of the field work. He has continually reported that there is a good flow of water from the tile outlet whenever the ground is saturated and also that, as a general rule, the soil on the tile-drained plots works more easily and keeps in better condition than that on the undrained plots. As a rule, the tile-drained land has produced larger yields than the undrained land, plot 101 being excepted for reasons mentioned above.

In 1896 very satisfactory weather conditions obtained and an excellent crop of corn was secured, especially on the drained land. Some benefit is strongly indicated from subsoiling on land not tile-drained.

In 1897, owing to drought and chinch bugs, the corn crop was a failure.

In 1898 a good crop of cow peas was grown, although very little effect is seen from drainage or from the previous subsoiling.

In 1899 the corn was markedly better on the tile-drained land, although the crop was poor. Nitrate of soda (sodium nitrate) applied to plots 5 and 6 at the rate of 300 pounds per acre, and to plot 7 at the rate of 200 pounds per acre, produced no apparent effect on yields of corn. (Nitrate of soda costs about $2.50 per hundred pounds.)

TABLE 1.—CROP YIELDS IN SOIL EXPERIMENTS. EDGEWOOD WEST FIELD.

Plot No.	Gray silt loam prairie, Lower Illinois Glaciation. Soil treatment applied.	Series 100. Not drained.	Series 200. Tile drained.
	1896—Corn, bushels per acre.		
1	None (cowpeas turned under)	Cowpeas.	Cowpeas.
2	None (buckwheat turned under)	Buckwheat.	Buckwheat.
3	None	34.9	37.7
4	None	42.5	54.3
5	None	41.7	51.2
6	None	37.0	50.9
7	Subsoiled	46.5	54.0
	1897—Corn, bushels per acre.		
1	Green manured (1896)	4.3	2.1
2	Green manured (1896)	1.9	1.4
3	None	3.7	3.7
4	None	8.5	8.1
5	None	11.4	15.9
6	None	10.2	12.9
7	None	6.4	8.7
	1898—Cowpeas, bushels per acre.		
1	None (cowpeas turned under)	Cowpeas.	Cowpeas.
2	None (buckwheat turned under)	Buckwheat.	Buckwheat.
3	None	18.8	19.6
4	None	21.5	22.9
5	None	22.3	26.3
6	None	14.6	22.5
7	None	14.9	17.3
	1899—Bushels corn per acre.		
1	Green manured (1898)	25.6	20.7
2	Green manured (1898)	15.4	16.4
3	None	11.4	16.5
4	None	12.3	26.0
5	Sodium nitrate	11.3	25.3
6	Sodium nitrate	12.9	22.8
7	Sodium nitrate	16.3	23.5
	1900—Oats, bushels per acre.		
1	None	34.0	22.0
2	None	33.0	38.5
3	None	30.0	30.0
4	None	36.0	36.5
5	None	40.0	36.0
6	None	36.0	31.5
7	None	36.0	36.0
	1901—Clover, tons per acre.		
1	None	.74	.28
2	None	.16	.14
3	None	.04	.05
4	None	.07	.09
5	None	.38	1.04
6	None	.27	.67
7	None	.24	.58

Table 1.—Continued.—Crop Yields in Soil Experiments. Edgewood West Field.

Soil plot No.	Gray silt loam prairie, Lower Illinois Glaciation. Soil treatment applied.	Series 100. Not drained.	Series 200. Tile drained.
	1902—Corn, bushels per acre.		
1	None	11.3	14.1
2	None	8.1	16.7
3	Legume	9.3	15.1
4	Legume, lime	11.3	24.9
5	Legume, lime, phosphorus	14:9	33.7
6	Legume, lime, phosphorus, potassium	17.1	32.1
7	Lime, phosphorus, potassium	21.5	33.2
	1903—Oats, bushels per acre.		
1	None	12.5	6.6
2	None	10.9	9.4
3	Legume	12.2	7.2
4	Legume, lime	21.2	16.2
5	Legume, lime, phosphorus	31.6	35.3
6	Legume, lime, phosphorus, potassium	24.4	37.5
7	Lime, phosphorus, potassium	20.6	35.0
	1904—Corn, bushels per acre.		
1	Manure	60.4	59.6
2	Manure	52.0	58.0
3	Legume	29.0	27.8
4	Legume, lime	40.9	44.4
5	Legume, lime, phosphorus	43.0	59.2
6	Legume, lime, phosphorus, potassium	52.5	62.1
7	Lime, phosphorus, potassium	52.6	61.3

In 1900 a good crop of oats was obtained, but there are no differences of special interest among the yields from the different plots, except, possibly, the discordant results from plots 1 and 2, as compared with the yields of corn for the previous year.

In 1901 the clover, which had been seeded with the oats in 1900, produced a very poor crop, but quite a marked increase in yield occurred on plots 5, 6 and 7, which had been treated with sodium nitrate two years previous. These results suggested to the writers the probable acidity of this type of soil. The nitrogen applied in the sodium nitrate was much less in amount than the nitrogen removed in the crops grown in 1899 and 1900, and it seemed very improbable that sufficient nitrogen should remain in the soil to affect a third crop, especially as it had produced no apparent effect upon either the corn or oats, although applied in perfectly soluble form.

Sodium nitrate contains 50 percent more sodium than nitrogen. Sodium is a strongly alkaline element, and most of this element would be

left in the soil when the nitrogen was removed by crops. This would unite with the soil acids, and in places may have been sufficient to correct the soil acidity to the depth of a few inches, thus making a much more suitable condition for the growth and multiplication of the nitrogen-gathering bacteria on the clover roots, in case there were any brought with the clover seed or any already present in the soil. Subsequent experiments with the use of lime on this soil type (referred to in the following pages) strongly confirms this theory as to the effect produced by the sodium. (In addition to this, sodium nitrate is a soluble mineral salt which possesses some corrosive power by which the mineral elements of plant food, phosphorus and potassium, might be liberated from the soil to some extent.)

It should be understood that the legume treatment for 1902 was cow peas seeded in the corn that season. Of course, they could not be expected to benefit the 1902 corn crop. The season was very dry and the cow peas made but little growth, consequently they produced little, if any, effect upon the oat crop in 1903. One marked effect from soil treatment in the 1902 crop is the higher yield produced by phosphorus on plot 5 as compared with plot 4, which was treated the same as plot 5, except for the phosphorus. Phosphorus made an average gain of 4.6 bushels of corn on the undrained land, and a gain of 13.7 bushels on the tile-drained land. A still more striking effect was produced by the tile drainage. On several plots the tile-drained land produced twice as much as the undrained land, the maximum increase being from 14.9 to 33.7, or a gain of 18.8 bushels, on plot 5.

The results obtained with oats in 1903 agree with the previous year's work in showing a marked increase by phosphorus, this gain amounting to 10.4 bushels of oats on the undrained land, and 19.1 bushels on the drained land. All tile-drained plots to which phosphorus had been applied yielded larger crops than the corresponding undrained plots, but it is noticeable that all plots not receiving phosphorus produced smaller yields on the tile-drained land than on undrained land. There seems to be no explanation for this, unless it is possibly in the fact that these tile-drained plots produced the larger yields of 1902 and consequently retained smaller amounts of available plant food for the 1903 crop.

In order to bring the rotation on the west field into line with the general system adopted for the three Edgewood fields, corn was again grown in this field in 1904, oats being grown upon the north field and a regular legume crop upon the east field, thus allowing each of the three crops to be grown every year.

The season of 1904 was a fairly satisfactory one for the corn crop. Even with some allowance for the fact that plot 101 is somewhat better land than the average of the field, as mentioned above and as indicated

by every year's results, the results obtained from the manure plots* strongly confirm the universal experience as to the very great value of farm manure upon this type of soil, although slightly better results were obtained where both phosphorus and potassium were applied, especially on tile-drained land. Aside from this most satisfactory result produced by the farm manure, there are three other results of much importance: (1) Lime (as ground limestone) added to the legume treatment increased the yield by 11.9 bushels on the undrained land and by 16.6 bushels per acre on the tile-drained land.† (2) Phosphorus produced an increase of 14.8 bushels on the tile-drained land, although only 2.1 bushels gain was produced by phosphorus on undrained land. (3) On undrained land potassium produced a gain of 9.5 bushels when used in connection with lime and phosphorus, although only 2 to 3 bushels gain was produced by potassium on the corresponding tile-drained plots. But perhaps the most important result obtained in 1904 is the marked effect of tile drainage upon this type of soil under certain conditions of treatment. If we disregard plot 101, tile drainage produced an appreciable gain in every case, excepting with legume treatment only on plot 3. (It may be stated here that the legume treatment on plot 3 previous to 1904 consisted of very poor catch crops of cow peas in 1902 and 1903, whose effect upon the soil would be very slight. On plots 4, 5, and 6, the legume catch crops have made better growth.) By far the most marked effect of tile drainage was on plot 5 (legume, lime, phosphorus), where a gain of 16.2 bushels of corn per acre was produced by the tile drainage. While final conclusions ought not to be drawn as yet, data are fast accumulating which tend to show that one of the important effects of tile drainage is to render more accessible to the plant the immense store of potassium existing in the subsoil. Where we have corrected the acid in the soil with ground limestone so that legumes grow better (the bacteria which live in the tubercles on the

*NOTE.—In the modified plan of the Edgewood experiments it was designed to reserve plot 1 (in each series) as a check plot, to which no special treatment should be applied, while plot 2 was to receive six tons of farm manure per acre every three years to be applied for the corn crop. (Our standard rate of applying farm manure on all regular soil experiment fields is two tons per acre per annum, all applied in one year in the rotation, usually preceding a corn crop.) Through a misunderstanding, manure was applied to plot 1 as well as to plot 2 in each series on the west field at Edgewood in the spring of 1904, and the rate of application was 12 tons per acre instead of 6 tons. Because of this, plot 3 is taken as the check plot, this plot having received no special treatment, excepting that in 1902 and 1903 it grew very poor catch crops of cow peas, which were turned under, and in 1904 a fair catch crop of cow peas which, however, were pulled and removed from the land. Hereafter no special treatment will be applied to 103 or 203.

†Attention is called to the fact, however, that plot 3 usually gave somewhat smaller yields than plot 4 in previous years, even before lime was applied.

roots of the legumes and get nitrogen from the air do not thrive in acid soils), and have then grown legume crops and catch crops, and have also applied phosphorus, as on plot 105, we have thus made provision for all plant food except potassium, but still the crop produced in 1904 (plot 105) was only 43 bushels of corn per acre. When potassium was added (plot 106) the yield was increased to 52.5 bushels, but where tile drainage was put in (plot 205) the yield was increased from 43 to 59.2 bushels without applying potassium, thus indicating that tile drainage not only enables the crop to obtain a good supply of potassium from the abundant store which is known to exist n the subsoil, but that still other benefits were produced by the tile drainage, for even where potassium was applied (plots 6 and 7) the tile-drained plots yielded nearly 10 bushels more than the corresponding undrained plots. The fact that every plot to which phosphorus has been applied (5, 6, and 7) has given a larger yield on tile-drained land during the entire three years, is certainly strong evidence in favor of tile drainage. To be sure, the tile may produce but little effect during dry seasons, when they are not needed to remove surplus water, or even during extremely wet seasons, when heavy rains are so frequent that even the tile-drained land remains saturated much of the time.

THE EAST FIELD AT EDGEWOOD.—This field consists of two series (300 and 400), of 10 plots each. A three-year rotation of corn, oats, and clover has been grown on this field during the past three years. The entire field is tile-drained. Commercial nitrogen in the form of dried blood has been used on certain plots, as indicated in the table. Phosphorus and potassium were applied in the same forms as used on the west field. The limed plots on series 300 received ground limestone, while those of the 400 series received fresh slaked lime.

The nitrogen, phosphorus and potassium were applied previous to the 1902 corn crop, but no lime was applied till after that crop had been harvested. Some previous differences were known to exist among the plots on this field, and these differences show very distinctly in the first corn crop. Plots 1 and 2 in each series had been given heavy applications of farm manure some years previous to 1902. By using plot 1 as a check plot and plot 2 for lime only, we avoid getting any exaggerated results from the other kinds of soil treatment, and, incidentally, have obtained some data relating to the lasting effect of farm manure.

Table 2 gives the yields of corn, oats, and clover from all of the plots on this field for three years. It will be noted that in 1903 the two series were harvested as one.

TABLE 2.—CROP YIELDS IN SOIL EXPERIMENTS. EDGEWOOD EAST FIELD.

Soil plot No.	Gray silt loam prairie, Lower Illinois Glaciation.	1902 Corn, bu.		1903 Oats, bu. average.	1904 Clover, tons.	
	Soil treatment applied.	Series 300.	Series 400.		Series 300.	Series 400.
1	None	40.9	44.3	33.9	1.13	2.33
2	Lime	34.8	47.7	40.6	1.70	2.18
3	Lime, nitrogen	20.9	23.1	39.1	1.68	2.01
4	Lime, phosphorus	25.7	22.8	42.8	1.93	2.00
5	Lime, potassium	22.1	32.4	38.3	1.55	2.01
6	Lime, nitrogen, phos.	21.6	25.2	41.1	2.36	2.91
7	Lime, nitrogen, potass.	17.7	13.6	37.2	2.17	2.61
8	Lime, phos., potassium	30.3	17.7	48.1	2.69	2.52
9	Lime, nit., phos., potass.	27.2	17.5	46.7	2.67	2.74
10	Nit., phos., potass.	27.9	15.9	49.1	1.88	2.39

No conclusions are to be drawn from the 1902 corn crop, aside from the fact that a marked effect was produced on plots 1 and 2, in each series, owing to the previous heavy application of farm manure already referred to. The crop suffered from a severe wind storm, and it was much injured by chinch bugs, especially on plots 7 to 10, in the 400 series.

The results obtained from the oat crop in 1903 show that the effect of the farm manure on plots 1 and 2 had been equaled or exceeded by the applications made to several other plots, especially where phosphorus was included in the treatment. Indeed, the crop yields for 1903 and 1904 are better appreciated when we bear in mind that in 1902 plots 1 and 2 produced a yield of corn 15 bushels higher than the yield of any other plot, as an average of both series, whereas in 1903 the oat crop on the check plot (No. 1) is 13 to 15 bushels lower than on the highest yielding plots (8, 9 and 10).

The results from the clover crop in 1904 are exceedingly interesting and valuable, even though some of the data are confusing and many questions are not fully settled. Of greatest importance, perhaps, is the simple fact that more than two and one-half tons per acre of well cured pure red clover hay were produced on some of these plots on soil which is very generally considered incapable of growing clover successfully. Indeed, many farmers who visited this experiment field expressed great surprise at seeing such a crop of clover, stating that they had never before seen clover grown so successfully on this type of soil. Aside from the special treatment given the different plots, it should be remembered that all of these plots are well tile-drained and that the clover was well inoculated with the proper nitrogen-gathering bacteria, by methods already explained in Bulletin No. 94, "Nitrogen Bacteria and Legumes," a copy of which will be sent to any one free of charge, upon application.

The individual plot yields indicate some things, but the single year's results do not justify definite conclusions. It will be observed, for example, that the 400 series yielded more than the 300 series, on most plots. One might suppose that this is due to the fact that burned lime was applied to the 400 series, while ground limestone was used on the 300 series; but this difference is marked on the unlimed plots (1 and 10), as well as on most of the limed plots. Plot 401, to which neither lime nor plant food had been applied, yielded 2.33 tons, as against 1.13 tons on plot 301. The only explanation suggested for this difference is the fact that plot 401 is nearest to the barnyard and probably has received more farm manure than any other plot in the field. The high yield on plot 402 may be due in part at least to the same reason. No explanation is offered for the difference between plots 310 and 410, as Mr. Bartley, who has owned and farmed this land for more than thirty years, is sure that no manure has been applied to any part of this field, aside from the first two or three plots in each series.

It would be expected that burned lime would produce a greater increase in the crops for the first year or two than would be produced by the ground limestone, more especially where the mineral elements, phosphorus and potassium, are not applied, for the reason that ground limestone produces practically no effect except to correct the acidity of the soil and thus encourage the multiplication and activity of the nitrogen-gathering bacteria, while the burned lime not only produces this same effect, but it also acts as a soil stimulant, or soil destroyer, attacking and destroying the organic matter and decomposing the mineral constituents, and thus liberating plant food from the soil. The use of ground limestone to correct acidity and increase the fixation of atmospheric nitrogen is certainly altogether legitimate and commendable, but to use burned lime to force the soil to give up plant food more rapidly than it would otherwise do, thus producing an increase in the first few crops, but ultimately leaving the soil more impoverished than before the lime was applied, is not thought to be advisable or profitable in the long run, unless the soil contains comparatively large stores of unavailable plant food and abundant organic matter, which is certainly not the case with this soil. It is perhaps worthy of notice that where lime, phosphorus, and potassium were all applied (plots 8 and 9), the yield of clover was about the same in each series, averaging slightly higher with the ground limestone; but where one or both of these elements were omitted, the yield was then larger where burned lime was used.

The north field at Edgewood is devoted to experiments to determine the comparative agricultural value of steamed bone meal and ground rock phosphate, applied in different amounts; and the east field and the north field combine experiments to determine the amounts of lime or

ground limestone which can be used with greatest profit on this soil. From the analysis of the soil and the results thus far obtained from field experiments, we recommend at least two tons to the acre of ground limestone. Larger applications will do no harm, but will probably produce quicker results and will certainly last longer. Probably it will be necessary to continue to apply ground limestone at the rate of a ton to the acre every five or six years, but further results are necessary to determine this point. The north field at Edgewood was started more recently than the other fields, and the data thus far obtained are not sufficient to justify their discussion at this time.

Plate 1 shows the red clover growing upon plot 304, to which ground limestone and steamed bone meal have been applied, which produced about two tons of clover hay to the acre.

Plate 2 shows the effect of lime upon the alfalfa growing upon one of the border strips of the Edgewood field, lime having been applied on the right, and no lime on the left. Similar results, showing the very marked benefit of lime or ground limestone upon alfalfa in several other places and also upon last spring's seeding of red clover on the north field, are sufficient to fully demonstrate the importance of using some form of lime for growing clover on this type of soil. (See, also, illustrations from DuBois field.)

PLATE 1.—CLOVER CROP WITH LIME AND PHOSPHORUS TREATMENT. EDGEWOOD SOIL EXPERIMENT FIELD, 1904.

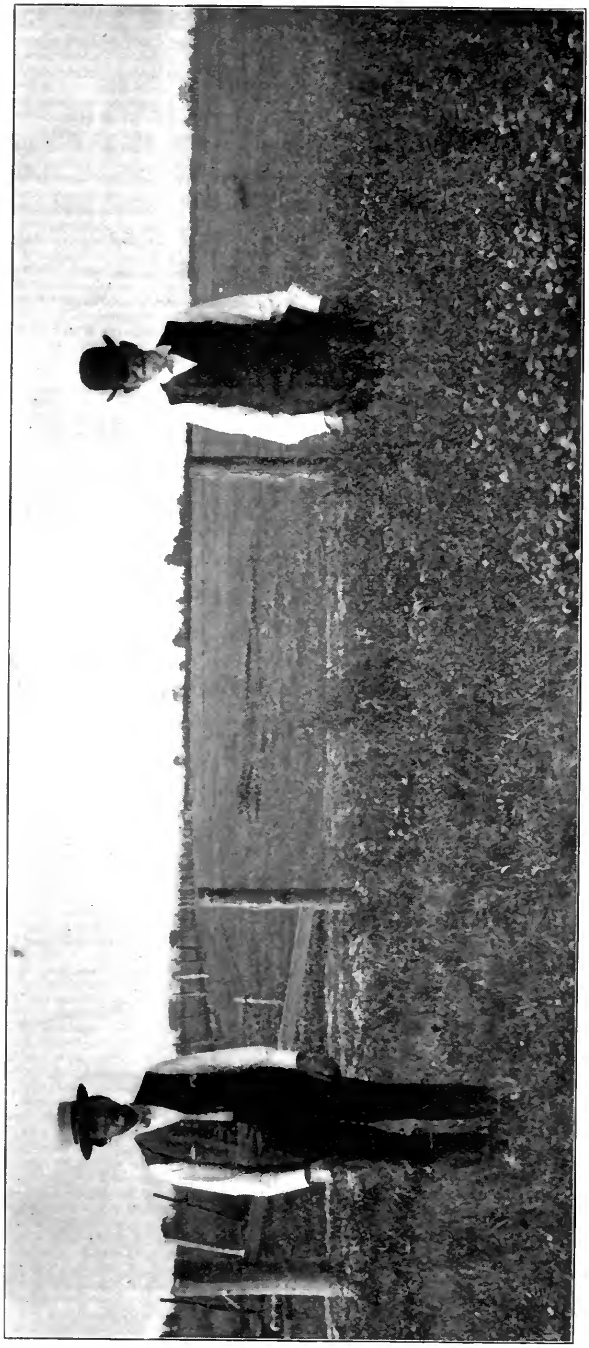


PLATE 2.—ALFALFA WITH LIME TREATMENT ON THE RIGHT, AND WITH NO TREATMENT ON THE LEFT EDGEWOOD SOIL EXPERIMENT FIELD, 1904.

THE ODIN FIELD.

The Odin Soil Experiment Field is located on the west side of the Illinois Central Railroad, about one mile southwest of Odin, Marion County, on the farm of Col. N. B. Morrison. The original field contains 40 fifth-acre plots, arranged in four series (100 to 400), of 10 plots each, one-half of each series (plots 1 to 5) is not drained, while the other half (plots 6 to 10) is tile-drained. Plots 1 and 2, especially in series 300 and 400, are better land than the average, being on the lower side of the field. All the remaining plots are believed to be fairly uniform.

A four-year rotation is being followed on the field:

First year, corn.

Second year, oats.

Third year, wheat.

Fourth year, cow peas.

In 1902 corn was grown in place of wheat in series 300. On plots 1 and 6 no treatment is applied. On all other plots cow peas are grown as a catch crop, in the corn, after the oats, and after the wheat, these catch crops always being turned under. During the first rotation (four years), the full crop of cow peas is also being turned under on these plots. Lime, phosphorus, and potassium are applied as indicated in Table 3.

In 1902 very poor crops were produced, drouth, chinch bugs, and poor soil combining to produce this effect. Some slight improvement is shown where phosphorus was applied, and where corn was grown the improvement with both phosphorus and potassium is more noticeable.

In 1903 the crops were even-poorer than in the previous year. (Hundreds of acres of wheat in southern Illinois were not cut.) Phosphorus produced a slight increase in the yield of oats and a very marked increase in the yield of wheat, especially on tile-drained land (plots 208 and 209), where the increase was from 2.1 bushels to 13.4 bushels, or a gain of 11.3 bushels. It will be observed that with legume-lime-phosphorus treatment, 5.8 bushels were obtained on undrained land, that this was increased to 13.4 bushels, or 7.6 gain, by tile drainage, and that it was increased to 14.0 bushels, or 8.2 gain, by adding potassium, thus suggesting that tile drainage may serve to aid the crops in drawing potassium from the large supply in the subsoil, by encouraging deeper rooting. This coincides with some similar indications seen in the results from the Edgewood field; but, aside from this single wheat plot and three plots of oats in 1904, no appreciable benefits have as yet resulted from the tile drainage at Odin. It is true that this tile has been in only three years and that tile usually becomes more and more effective for eight or ten years; also that the first two years were almost crop failures, with very little rainfall, and the third year so wet that even the tile-drained land contained too much water most of the time. It would be premature to draw any definite conclusions at this time as to the value

TABLE 3.—CROP YIELDS IN SOIL EXPERIMENTS: ODIN FIELD.

Odin soil plot No.	Gray silt loam prairie, Lower Illinois Glaciation.	Series 100.		Series 200.		Series 300.		Series 400.	
		Not drained. (1 to 5.)	Tile-drained. (6 to 10.)	Not drained. (1 to 5.)	Tile-drained. (6 to 10.)	Not drained. (1 to 5.)	Tile-drained. (6 to 10.)	Not drained. (1 to 5.)	Tile-drained. (6 to 10.)
	Soil treatment applied.	1902 Corn, bu.		1902 Oats, bu.		1902 Corn, bu.		1902 Cow Peas.	
1 and 6	None	12.1	11.5	15.8	12.2	19.5	7.5	removed	removed
2 and 7	Legume	7.2	13.5	16.1	10.3	10.7	10.0	turned	turned
3 and 8	Legume, lime	8.8	9.7	14.1	11.7	8.8	10.0	turned	turned
4 and 9	Legume, lime, phosphorus	4.9	9.5	16.7	19.2	10.7	15.6	turned	turned
5 and 10	Legume, lime, phos., potass.	14.4	20.7	18.8	17.7	14.5	16.3	turned	turned
		1903 Oats, bu.		1903 Wheat, bu.		1903 Cow Peas.		1903 Corn, bu.	
1 and 6	None	6.9	8.1	.4	.6	removed	removed	17.9	8.7
2 and 7	Legume	5.2	8.8	.6	.6	turned	turned	16.6	12.8
3 and 8	Legume, lime	6.3	7.3	.7	2.1	turned	turned	20.2	17.6
4 and 9	Legume, lime, phosphorus	8.6	12.3	5.8	13.4	turned	turned	18.3	15.9
5 and 10	Legume, lime, phos., potass.	25.8	28.9	14.0	15.2	turned	turned	22.3	15.0
		1904 Wheat, bu.		1904 Cow Peas.		1904 Corn, bu.		1904 Oats, bu.	
1 and 6	None	7.9	6.7	removed	removed	53.1	29.4	28.6	25.1
2 and 7	Legume	5.4	8.5	turned	turned	48.8	31.6	36.7	33.4
3 and 8	Legume, lime	10.7	9.6	turned	turned	44.1	42.8	41.4	53.3
4 and 9	Legume, lime, phosphorus	21.6	21.5	turned	turned	44.1	45.9	39.8	44.8
5 and 10	Legume, lime, phos., potass.	24.4	25.4	turned	turned	66.6	64.1	39.7	43.1

of tile drainage in this soil. One thing, however, is sure: When the ground is saturated with water, a good stream flows out of the tile, at Edgewood, at Odin, and at DuBois. Greater benefits from tile drainage may be obtained, perhaps, after a deep rooting biennial crop, like red clover, has been grown. (After next season, cow peas are to be substituted for oats and red clover for the fourth year cow peas, in the rotation at Odin, making the rotation corn, cow peas, wheat, and clover.)

Referring again to Table 3, it will be seen that the oat crop in 1903 was markedly benefited by the addition of potassium to the other treatment, the yield being increased by 17.2 bushels on undrained land and by 16.6 bushels on the tile-drained land.

In 1904 favorable weather conditions prevailed, aside from the excessive rainfall, which during the spring and early summer was more than could be removed by the tile under present conditions. The wheat was considerably damaged by rust, more especially on the better plots. Some very marked results were obtained from the use of phosphorus for wheat, the yield being increased from about 10 bushels to 21.5 bushels, making a gain of 11 bushels on undrained land and 12 bushels on tile-drained land. According to the wheat buyer's grading, the phosphorus also inproved the quality of the wheat, so that the selling price was advanced from 80 cents to 90 cents a bushel. Potassium produced an additional gain of more than 3 bushels and advanced the selling price to 95 cents a bushel. With corn and oats, phosphorus produced no appreciable effect, but a noticeable increase was produced by lime on both corn and oats, and a good gain was made on the oat crop by the legume treatment alone; but the most marked effect was produced by the potassium on the corn crop, the yield of corn being increased on undrained land from 44.1 to 66.6, a gain of 22.5 bushels, and, on the tile-drained land, from 45.9 to 64.1, a gain of 18.2 bushels, making an average gain of more than 20 bushels. It is especially instructive to note the difference in yield between the crops on the untreated plots and those receiving full treatment. For this comparison the tile-drained plots are the more reliable, as they are more nearly uniform.

Thus, the yield of wheat was increased from 6.7 to 25.4, a gain of 18.7 bushels. Furthermore, the yield of wheat was increased in 1903 from .6 to 15.2, a gain of 14.6 bushels, making a total increase of 33.3 bushels in two years. The yield of corn was increased from 29.4 to 64.1, a gain of 34.7 bushels. In 1902 the yield of corn was increased 9.2 bushels on one series and 8.9 bushels on the other; and in 1903 it was increased 6.3 bushels. This would make 24.4 bushels, or a total gain of 59.1 bushels for the four crops. The yield of oats was increased from 25.1 to 43.1, a gain of 18 bushels. In 1902 the yield of oats was increased 5.5 bushels, and in 1903 it was increased 20.8 bushels. This would make 26.3 bushels, or a total gain of 44.3 bushels in three years.

PLATE 3.—WHEAT CROP (2.1 bu.) WITH LEGUME AND LIME TREATMENT: ODIN SOIL EXPERIMENT FIELD, 1903.

PLATE 5.—WHEAT CROP (9.6 bu.) WITH LEGUME AND LIME TREATMENT: ODIN SOIL EXPERIMENT FIELD, 1904.

PLATE 4.—WHEAT CROP (13.4 bu.) WITH LEGUME, LIME, AND PHOSPHORUS TREATMENT: ODIN SOIL EXPERIMENT FIELD, 1903.

PLATE 6.—WHEAT CROP (21.5 bu.) WITH LEGUME, LIME, AND PHOSPHORUS TREATMENT: ODIN SOIL EXPERIMENT FIELD, 1904.

PLATE 7.—CORN CROP (29.4 bu.) WITH NO SOIL TREATMENT: ODIN SOIL EXPERIMENT FIELD, 1904.

PLATE 8.—CORN CROP (64.1 bu.) WITH LEGUME, LIME, PHOSPHORUS, POTASSIUM TREATMENT: ODIN SOIL EXPERIMENT FIELD, 1904.

PLATE 9.—COW PEA CROP WITH NO SPECIAL SOIL TREATMENT: ODIN SOIL EXPERIMENT FIELD, 1904.

As shown in Table 3, the cow pea crop was turned under on all plots except the checks, the plan being to turn under one full crop of cow peas on each series for the benefit of the land, this being in addition to the catch crops grown. It was observed, however, that the cow pea crop responds to soil treatment as markedly as any other crop, being especially benefited by the addition of limestone and potassium. In order to obtain some data as to the effect of soil treatment on cow peas, one-thousandth acre plots were harvested from several field plots in 1904. Plot 207, with only legume treatment, produced 3.4 bushels of shelled peas per acre; while plot 210, with legume, lime, phosphorus, potassium treatment, produced 22.3 bushels per acre, a gain of 19.1 bushels. The three years' results from corn, oats, and wheat are summarized in Table 4.

Plate 10.—Cow Pea Crop with Legume, Lime, Phosphorus, Potassium Treatment: Odin Soil Experiment Field, 1904.

Table 4.—Total Yields for Three Years: Odin Soil Experiment Field.

Soil treatment.	Corn, bu.	Oats, bu.	Wheat, bu.
None	57.0	45.4	7.3
Legume, lime, phosphorus, potassium	116.1	89.7	40.6
Increase	59.1	44.3	33.3

It will be seen that the effect of the full treatment has been to more than double the yield of corn, to nearly double the yield of oats, and to produce a total yield of wheat five and one-half times as large as was produced on the untreated land. Furthermore, the untreated land is growing poorer, while the treated land is growing richer, much more plant food having been applied than has been removed in the crops. This subject will be discussed more fully after the data from the DuBois and Cutler fields have been given.

THE DUBOIS FIELD.

The DuBois Soil Experiment Field is located about one mile northwest of DuBois (Bois Station), Washington County, on the farm of Mr. A. A. Hinkley. It contains 20 tenth-acre plots, arranged in two divisions of 10 plots each, one division being tile-drained and the other not drained. A four-year rotation is being followed upon this field, namely:

First year, corn.
Second year, oats.
Third year, wheat.
Fourth year, clover.

The clover is seeded on the wheat land in the spring of the third year.

The soil treatment applied and the crop yields obtained during the first three years are shown in Table 5.

TABLE 5.—CROP YIELDS IN SOIL EXPERIMENTS: DUBOIS FIELD.

Soil plot No.	Gray silt loam prairie. Lower Illinois Glaciation.	1902 Corn, bu.		1903 Oats, bu.		1904 Wheat, bu.	
	Soil treatment applied.	Not drained.	Tile-drained.	Not drained.	Tile-drained.	Not drained.	Tile-drained.
1	None	6.4	1.5	9.4	17.2	6.3	3.3
2	Lime	6.7	3.3	16.2	17.2	6.5	11.5
3	Lime, nitrogen	5.9	2.7	18.1	20.6	11.0	9.2
4	Lime, phosphorus	13.5	6.5	25.9	27.5	25.0	28.3
5	Lime, potassium	11.6	4.9	27.5	27.2	16.2	14.7
6	Lime, nit., phos.	9.3	8.0	25.0	33.8	32.7	31.2
7	Lime, nit., potassium	6.8	7.3	23.8	27.2	20.2	23.3
8	Lime, phos., potassium	12.4	14.1	30.0	25.6	27.5	32.2
9	Lime, nit., phos., potass.	10.4	10.4	29.1	31.9	33.3	30.5
10	Nit., phos., potass.	2.0	4.8	25.6	33.1	27.3	28.2
Average gain for nitrogen		-3.0	.1	-1.0	4.1	5.5	1.9
Average gain for phosphorus		3.9	5.2	6.1	6.7	16.2	15.9
Average gain for potassium		1.4	4.1	6.3	3.1	5.5	5.1

By "average gain" is meant the average of four trials with the elements named. Thus, by comparing the yields of wheat from plots 2 and 4 on the tile-drained division in 1904 (last column), it will be seen that the addition of phosphorus increased the yield of wheat from 11.5 on plot 2 to 28.3 on plot 4, a gain of 16.8 bushels for the phosphorus applied. Comparing the yields from plots 3 and 6, we see that phosphorus, added to lime and nitrogen, made a gain of 22 bushels of wheat to the acre. Phosphorus made a gain of 17.5 bushels on plot 8, as compared with plot 5, and a gain of 7.2 bushels on plot 9 as compared with plot 7. The total gain from the four tests is 63.5 bushels, or an average gain of 15.9 bushels of wheat per acre, due to the phosphorus applied, as stated in the table.

It will be observed that the 1902 corn crop was a failure, 14.1 bushels being the highest yield obtained, and the oat crop in 1903 was also very poor, so that no conclusions can be drawn from the first two years' work, although phosphorus seems to rank first when the average gains made by each of the three elements are compared.

The 1904 wheat crop was fairly satisfactory, although it was much damaged by rust, especially on the better yielding plots. Phosphorus produced very marked gains in the yield of wheat, averaging 16 bushels gain for eight separate tests. The gain for nitrogen was 3.7 bushels, and for potassium 5.3 bushels, as an average of eight separate tests with each element. The lime-nitrogen treatment on plot 3 corresponds to legume-lime treatment on our rotation experiments, where the legume treatment is depended upon to supply the nitrogen. The growing of legumes (mostly cow peas) with the hope of thus improving this southern Illinois soil is a somewhat common practice, and some ground limestone is already being used to correct the acidity of soil and thus to encourage the nitrogen-gathering bacteria and make the growing of legumes, especially of red clover, more successful. It may be definitely stated, even at this early date, and without hesitation or doubt, that a liberal use of lime and legumes will be an essential part of any practical and economical system that ever becomes successful in the permanent improvement of southern Illinois soil. This being granted, it is of especial interest and importance to note the marked effect produced by adding phosphorus to lime and nitrogen. By comparing plots 3 and 6, it will be observed that phosphorus produced some gain every year on both undrained and tile-drained land, 3.4 and 5.3 bushels of corn in 1902, 6.9 and 13.2 bushels of oats in 1903, and 21.7 and 22 bushels of wheat in 1904, all of which tends to prove that a liberal use of the element phosphorus must be included in the plan for improving this soil, especially for wheat growing. The wheat grower will be interested to know that the quality or market value of the wheat was also markedly improved by phosphorus. According to the grain buyer at DuBois, the wheat from plots 106 and 206 (averaging 32 bushels per acre), was worth 15 cents more per bushel than the wheat from plots 103 and 203 (averaging 10 bushels per acre).

Clover was seeded with the oats on the DuBois field in 1903, and a very good stand was obtained, but most of it died even before the oats were cut. A careful examination showed that the soil did not contain the red clover bacteria, as no tubercles could be found upon the clover roots. The field was inoculated about the first of July with infected red clover soil, and this may have been some help to the clover still living at that time, and the clover, although a poor stand, doubtless helped the bacteria to multiply somewhat, so that the soil became well infected. The field was plowed and seeded to wheat in the fall of 1903,

PLATE 11.—FIRST YEAR CLOVER (MOSTLY FOUL GRASS) WITH NO SPECIAL SOIL TREATMENT: DUBOIS SOIL EXPERIMENT FIELD, 1904 (AUTUMN).

and clover again seeded in the spring of 1904. A good stand was obtained and, with the exception of the unlimed check plots, a very satisfactory growth was made during the season of 1904, and the clover was found to be well provided with root tubercles. On the unlimed check plots most of the clover died during the season. Of course, no clover yields will be obtained till next season, but Plates 11 and 12 show the condition of the clover in the fall of 1904. It will be seen that on the check plot, where no lime was applied, there is only a scanty growth of foul grass and weeds, while a good growth of clover is seen on the limed plot.

Plate 12.—First Year Clover ("Knee Deep") with Lime Treatment: DuBois Soil Experiment Field, 1904 (Autumn).

The Cutler Field.

The Cutler Soil Experiment Field is located about five miles northwest of Cutler, Perry County, on the farm of Mr. W. E. Braden. The original field contains 40 fifth-acre plots. Thirty of these are in three divisions of 10 plots each, for a three-year rotation of wheat, corn, and cow peas. On certain plots a catch crop of cow peas is also grown after the wheat and with the corn. The other 10-plot series is used for a "complete fertility test," some nitrogen having been purchased for use on this field. A four-year rotation of corn, oats, wheat, and clover is followed on this series. The soil treatment and crop yields for the individual plots are shown in Tables 6 and 7. None of the Cutler field is tile-drained.

TABLE 6.—CROP YIELDS IN SOIL EXPERIMENTS: CUTLER FIELD.

Soil plot No.	Gray silt loam prairie, Lower Illinois Glaciation.	Bushels per acre.		
	Soil treatment applied.	1902.	1903.	1904.
		Cow Peas.	Wheat.	Corn.
201	None	removed	6.0	22.8
202	Legume	turned	9.2	24.7
203	Manure	removed	12.1	36.9
204	Legume, lime	turned	13.5	30.6
205	Manure, lime	removed	13.3	44.1
206	Legume, lime, phosphorus	turned	20.3	30.6
207	Manure, lime, phosphorus	removed	20.8	30.9
208	Legume, lime, phosphorus, potass.	turned	26.8	60.0
209	Manure, lime, phosphorus, potass.	removed	24.0	70.9
210	Lime, phosphorus, potass.	removed	21.1	71.9
		Oats.	Cow Peas.	Wheat.
211	None	19.6	removed	9.0
212	Legume	23.8	turned	8.5
213	Manure	26.6	removed	18.2
214	Legume, lime	26.9	turned	8.8
215	Manure, lime	27.8	removed	18.4
216	Legume, lime, phosphorus	28.0	turned	14.3
217	Manure, lime, phosphorus	25.2	removed	19.7
218	Legume, lime, phosphorus, potass.	31.1	turned	16.4
219	Manure, lime, phosphorus, potass.	28.8	removed	19.7
220	Lime, phosphorus, potass.	26.7	removed	15.0
		Wheat.	Corn.	Cow Peas.
221	None	12.8	4.0	removed
222	Legume	12.4	3.7	turned
223	Manure	12.4	3.5	removed
224	Legume, lime	13.3	3.7	turned
225	Manure, lime	12.9	3.6	removed
226	Legume, lime phosphorus	16.9	2.4	turned
227	Manure, lime, phosphorus	16.1	2.1	removed
228	Legume, lime, phosphorus. potass.	20.8	3.7	turned
229	Manure, lime, phosphorus, potass.	19.4	6.1	removed
230	Lime, phosphorus, potass.	20.8	9.2	removed

Manure is applied for wheat after cow peas. Plots 203, 205, 207 and 209 were manured for the 1903 wheat crop, plots 213, 215, 217 and 219 for the 1904 wheat crop, and plots 223, 225, 227 and 229 for the 1905 wheat crop. Thus, no crop grown in 1902 had received manure or legume treatment. During the first course of the rotation one full crop of cow peas has been turned under on all plots receiving legume treatment, but afterward the legume treatment consists of catch crops only. Lime was not applied to plots 224 to 230 till after the 1902 wheat crop had been harvested. Oats were substituted for corn in 1902 on plots 211 to 220.

In 1902 phosphorus increased the yield of wheat from 12.8 (average of five untreated plots), to 16.5, a gain of 3.7 bushels, and potassium further increased the yield from 16.5 to 20.3, a gain of 3.8 bushels, but no appreciable effect was produced on the oat crop.

In 1903 the corn crop was a failure on the Cutler field, owing to the drouth. On the other hand, some very satisfactory results were obtained with wheat, the maximum increase being from 6 bushels, with no treatment, to 26.8 bushels, with legume-lime-phosphorus-potassium treatment, a gain of 20.8 bushels of wheat, the credit for this increase being divided as follows: 3.2 for legume treatment, 4.3 for lime, 6.8 for phosphorus, and 6.5 for potassium. With the manured plots the total gain was 18 bushels, divided as follows: 6.1 for manure alone, 1.2 for lime, 7.5 for phosphorus, and 3.2 for potassium. Lime-phosphorus-potassium treatment made a gain of 15.1 bushels, without manure or legume turned under.

In 1904 the wheat was much injured by rust, especially on the best treated plots. Manure alone made a gain of 8.4 bushels. Phosphorus gained 5.5 bushels on the legume plot. These are the most marked effects from the treatment, but no conclusions can be drawn, owing to the great damage from rust, which probably reduced the yield fully one-half on some plots. The corn crop, however, was fairly satisfactory. The manure applied in 1902 still shows some effect in 1904, although the results are discordant. The most marked and positive result is the large increase produced by potassium, the average increase being from 30.8 to 67.6, or a gain of 36.8 bushels of corn per acre for the element potassium. On the undrained land at Odin potassium gained 22.5 bushels of corn, and on the undrained land at Edgewood potassium gained 8.5 bushels. An average of these three tests in 1904 makes a gain of 22.6 bushels of corn to the acre for this element potassium. At 40 cents a bushel, this corn would be worth $9.04. The potassium applied to these fields during the past three years amounts to 160 pounds of that element. At 6 cents a pound, this has cost $9.60 an acre. With one exception, small gains were made by potassium on all of these fields in 1902 and 1903, so that the increased crop yields have fully paid for all the potassium which has been used on those plots which grew corn in 1904, but this is not true with plots which did not grow corn in 1904, and which have also received potassium. Consequently, it is still an open question whether the purchase of commercial potassium for use on this soil will be profitable. By studying the plant food taken from the soil by different crops, as given on page 4 of Circular 68, also the yield of crops from these different fields, as reported in this bulletin, it will be seen that about one-half of the potassium which has been applied to these fields still remains in the soil, so that the soil is growing richer instead of poorer. It should also be remembered that it takes

some time to get the full benefit of soil treatment, especially of rotation of crops. We cannot practice a four-year rotation in one year's time. Indeed, it really takes four years to get such a rotation properly started. The second four-years' course should show some of the benefits, but the full benefits should not be expected before the third four-years' course.

It is true that the effect of potassium on the 1904 corn crop was extremely marked, but it is also true that the season of 1904 was extremely abnormal in southern Illinois. During most of the growing season the frequent and heavy rains kept the ground soaked so full of water that the feeding range of the plant roots was limited to a few inches of surface soil. It is conceivable that a liberal supply of readily available potassium in these few inches of soil would be of tremendous advantage to the plant under such conditions, a good supply of the other plant food elements also being provided, as was the fact in all cases. This much we know with certainty from the chemical analysis of this soil, namely, that it actually contains moderate amounts of potassium in the surface, and large amounts of potassium in the subsoil, and these investigations must be continued until we learn definitely whether we cannot draw potassium from that immense store more cheaply than we can obtain it from the mines of Germany. Decaying organic matter, such as farm manure and green manures, will help to liberate potassium from the soil. Deep rooting plants, especially biennial plants like red clover, and perennial plants like alsike clover, which have strong feeding powers, will help to obtain potassium from the soil and to bring it up from the subsoil, and we already have some evidence that tile drainage will help to make the potassium in the subsoil more available.

TABLE 7.—CROP YIELDS IN SOIL EXPERIMENTS: CUTLER FIELD.

Soil plot No.	Gray silt loam prairie, Lower Illinois Glaciation.	Bushels per acre.		
	Soil treatment applied.	1902 Corn.	1903 Oats.	1904 Wheat.
1	None	6.8	15.2	9.0
2	Lime	5.2	13.7	10.5
3	Lime, nitrogen	1.2	16.6	9.8
4	Lime, phosphorus	3.5	14.2	21.9
5	Lime, potassium	2.9	18.0	10.0
6	Lime, nitrogen, phosphorus	2.2	20.3	15.8
7	Lime, nitrogen, potassium	2.8	20.0	8.2
8	Lime, phosphorus, potassium	10.2	27.5	22.4
9	Lime, nitrogen, phosphorus, potas.	4.6	28.7	17.7
10	Nitrogen, phosphorus, potas.	5.4	37.7	15.0
Average gain for nitrogen		—2.8	+5.0	—4.9
Average gain for phosphorus		+2.1	+5.6	+9.8
Average gain for potassium		+2.4	+7.4	+ .1

The other division of the field at Cutler contains 10 plots in the "complete fertility test." A four-year rotation of corn, oats, wheat, and clover is being grown upon this field. The treatment applied and the crop yields obtained are shown in Table 7.

The corn crop grown in 1902 was almost a complete failure, chiefly because of the drouth, although some damage was caused by chinch bugs, 10.2 bushels per acre being the highest yield.

In 1903 a light crop of oats was produced. Appreciable gains were made by applications of plant food, especially by phosphorus and potassium combined. The lime applied in 1902 was found to be insufficient to correct the acidity of the soil, and a heavier application was made for 1903. There is some evidence that the effect of this was to reduce the yield of oats, and this might be expected, especially where phosphorus has been applied. Similar effects have been observed at times in pot-culture experiments, but the injurious effect is temporary and really emphasizes the importance of applying lime some months before the crop is to be grown, or of plowing under the phosphorus and then applying the lime to the plowed soil, the effect of lime in intimate contact with phosphorus being to hold the phosphorus in an insoluble form. We already have conclusive evidence that heavy applications of some form of lime must be used on this soil for the successful growing of legume crops, especially the clovers and alfalfa, and certainly we can never hope to restore and profitably maintain the fertility of this soil without legumes.

In 1904 the best wheat plots were much injured by rust, on this part of the Cutler field, as well as on the other. The only noteworthy result of soil treatment is the marked effect produced by the element phosphorus. As an average of four separate trials, phosphorus made a gain of 9.8 bushels of wheat.

General Average Increase.

While the data obtained from these three years' work do not justify us in drawing final conclusions, yet it seems worth while to make some general averages of the effects produced by each of the three plant food elements, bearing in mind as we consider them, that the first two years were seasons of severe drouth, especially for corn at Odin, DuBois, and Cutler, and that the last year (1904) until midsummer, was one of the wettest seasons ever known in southern Illinois.

Table 8 shows the average increase in bushels of corn, oats, and wheat produced by nitrogen, phosphorus and potassium, the total number of separate tests or trials being mentioned in each case.

Every individual test which has been made on this type of soil and reported in the preceding pages to determine the effect of each of these three elements, either alone or in combination, is represented in the averages given in Table 8.

TABLE 8.—INCREASE IN CROP YIELDS IN SOIL EXPERIMENTS, AVERAGE TESTS ON ALL FIELDS ON GRAY SILT LOAM PRAIRIE SOIL OF THE LOWER ILLINOIS GLACIATION.

Soil treatment applied.	Corn.		Oats.		Wheat.		Average value of increase.	Total number of tests.
	Bu. increase.	No. of tests.	Bu. increase.	No. of tests.	Bu. increase.	No. of tests.		
Nitrogen....	—3.5	16	+1.2	16	+ 1.4	12	$0.02	44
Phosphorus..	+1.8	32	+5.3	25	+11.2	21	3.27	78
Potassium...	+5.3	32	+4.2	25	+ 3.6	21	1.81	78

It will be seen that the average yield of corn has been reduced 3.5 bushels by nitrogen, increased 1.8 bushels by phosphorus, and increased 5.3 bushels by potassium.

The average yield of oats has been increased 1.2 bushels by nitrogen, 5.3 bushels by phosphorus, and 4.2 bushels by potassium.

The average yield of wheat has been increased 1.4 bushels by nitrogen, 11.2 bushels by phosphorus, and 3.6 bushels by potassium.

If we consider corn worth 35 cents a bushel, oats 25 cents a bushel, and wheat 70 cents a bushel, then the average value of the increase produced by nitrogen is 2 cents an acre a year, as an average of the three crops including 44 separate tests; the average value of the increase produced by phosphorus is $3.27 an acre a year, including 78 separate tests; and $1.81 an acre a year is the average value of the increase produced by potassium, 78 separate tests being included.

The present retail price of good steamed bone meal in southern Illinois, containing 12½ percent of phosphorus, is about $25 a ton. At this rate 25 pounds of phosphorus or 2 pounds more than would be removed in a 100-bushel crop of corn, would cost $2.50.

At $50 a ton for potassium chlorid (the cheapest commercial form of potassium) which contains about 42 percent of that element, the 71 pounds of potassium removed in a 100-bushel crop of corn would cost about $4.20.

At the same prices the 11 pounds of phosphorus removed by a 75-bushel crop of oats would cost $1.10, and the 49 pounds of potassium for the same crop would cost $2.94; the 12½ pounds of phosphorus for a 50-bushel wheat crop would cost $1.25, and the 56 pounds of potassium required for the same crop would cost $3.36.

It will thus be seen that if we consider the plant food requirements of these crops and the present prices of phosphorus and potassium and the increased crop yields which those elements have produced as an average of 78 tests each, we can very profitably make use of phosphorus in steamed bone meal in sufficient quantities to maintain such maximum crop yields, but it is not so evident that commercial potassium can be used with profit.

Raw rock phosphate containing 250 pounds of phosphorus to the ton

is as rich as good steamed bone meal and can be obtained in carload lots delivered at any railroad station in southern Illinois for about $8.00 a ton, or one-third the price of steamed bone meal. When used in combination with decaying organic matter, raw rock phosphate promises to be the most economical form of phosphorus to purchase and use on this soil.

THE CIRCULATION OF PLANT FOOD.

From two-thirds to three-fourths of the phosphorus removed in the above-named crops is contained in the grain, while only one-fourth to one-third is contained in the stover or straw. If the grain is sold, the larger part of the phosphorus is sold with it. If the crops are fed to growing animals, about 20 to 30 percent of the phosphorus is used in the formation of bones, and these are sold with the animals. That the element phosphorus is already deficient in this soil has been shown by chemical analysis and confirmed by pot cultures and by many field experiments each year for three successive years, and there is no system of farming which can be followed by all farmers which does not continually remove phosphorus from the farm. (Butter is the only common farm product which contains no appreciable amount of phosphorus.)

Regarding potassium there are some interesting points to be considered. The chemical composition of this soil shows that it is moderately well supplied with that element, even in the top soil, and that the subsoil is rich in potassium. Whether sufficient potassium for the most profitable crop yields can be liberated from the soil by the use of decaying organic matter, deep rooting crops, tile drainage, etc., is not yet determined. (Some extensive experiments with subsoiling are included in plans for continuing the investigation of this soil type.)

About three-fourths of the potassium removed from the soil by crops of corn, oats, or wheat is contained in the stalks or straw, while only one-fourth is contained in the grain. If the crops are fed on the farm, practically all of the potassium remains in the solid and liquid manure, and it may thus be returned to the land. Because of these facts, it thus becomes possible to use potassium again and again if we practice a live stock system of farming and carefully save and return to the land all of the farm manure. Even if we sell some of the most valuable grains, such as wheat, but feed the corn and oats and all coarse feed, using sufficient bedding to absorb and retain all liquid manure, we would still lose but very little potassium from the farm. This being true, it may ultimately prove profitable to maintain in the soil a liberal supply of available potassium, even though it may be necessary to make heavy initial applications of commercial potassium, and afterward to restore from time to time as much as is sold or lost from the farm, but further investigations are needed to determine this.

It is good farm practice to remove large quantities of plant food from the soil, for the simple reason that large crops require large quantities of plant food; but it is no less important to restore to the soil when needed as large or larger quantities of plant food as are removed—by turning under catch crops and crop residues not removed from the field, by returning manures produced on the farm, and so far as necessary by the purchase of commercial plant food, such as phosphorus in bone meal or rock phosphate, or potassium in potassium chlorid or potassium sulfate. Thus the most important process in all farm operations is the *circulation of plant food*, without which the fertility of cropped soils cannot be permanently maintained.

RECOMMENDATIONS CONCERNING SOIL TREATMENT FOR THE LOWER ILLINOIS GLACIATION.

FARM MANURE.

So far as possible all general farm crops, excepting the most valuable grains, should be fed to live stock. Plenty of bedding should be used and all solid and liquid manure thus saved and returned to the land. A live stock system of farming is very much more important for this soil at the present time than for the richer soils of the corn belt.

It is scarcely necessary to dwell upon the great value of farm manure for use on this soil. Indeed, the farmers of southern Illinois commonly appreciate the value of farm manure much more fully than do the farmers in the central and northern parts of the state. As a rule, the farm manure produced in southern Illinois is carefully saved and used, and the only insurmountable difficulty of restoring all the soil of the Lower Illinois Glaciation to a high state of fertility by the use of farm manure is the simple fact that all the manure now being produced in southern Illinois is barely sufficient to manure the garden patches. The crops grown on that soil without the use of imported plant food, even though they were all fed to live stock, would never produce sufficient manure to make that land rich.

LEGUMES AND LIME.

While it is true that nitrogen is not the element which first limits the yield of crops upon this soil, it is also true that the fertility of the soil cannot be satisfactorily increased and permanently maintained without some provision of maintaining the supply of nitrogen. The most economical and rational method of restoring and maintaining the supply of nitrogen is by means of legume crops, and legumes should certainly be given a prominent place in any system of crop rotation adopted on this land. But clover and other valuable legume crops cannot be grown in strongly acid soils with full success owing to the fact that the nitrogen-fixing bacteria are not sufficiently active and effective in such soils.

As a result of chemical analysis and of the field experiments thus far performed, it is recommended that at least two tons per acre of ground limestone be applied to this soil previous to sowing legumes. For the best results, it is believed that this should not be plowed under, but rather applied after plowing and mixed with the surface soil by disking, harrowing, and cultivating. If applied after the soil is plowed for corn, the limestone becomes thoroughly mixed with the soil by the time the corn is laid by. The corn may be followed by cow peas or soy beans or by wheat or oats and the land then seeded to clover.

Unless it is known that the soil is already infected with the proper nitrogen-fixing bacteria, it should of course be inoculated. The surest and simplest method of inoculation for clover is to obtain some thoroughly infected soil from an old clover field wherever tubercles are found in abundance on the clover roots. In most vicinities, some good patches of clover can be found within hauling distance on some old feed lot or patch of timber land or bottom land. About 100 pounds to the acre of thoroughly infected soil scattered over the land broadcast about the time the clover is seeded will usually produce a satisfactory inoculation if the soil is in suitable condition, although several hundred pounds may well be used if the expense is slight. Farmers are strongly advised against buying any patent artificial bacteria cultures with which to make inoculating solutions. Artificial cultures have been used in comparison with the natural soil method for about fifteen years, but the combined evidence of all comparable data thus far reported is strongly in favor of using the natural soil method. Ten years ago German promoters established commercial laboratories and endeavored to sell artificial cultures of nitrogen-fixing bacteria to the farmers. Just now American promoters are trying to sell artificial cultures to American farmers. One 1905 Seed Catalogue advertises as follows:

"NITRO-CULTURE.
"A Wonderful Discovery.
"**Doubles the Yield.**
"Insures Crops of Alfalfa and other Leguminous Plants on all Soils.

"Price, postpaid, pkg., sufficient for one acre, $2.00."

While it is true that the inoculation of legumes on suitable soils, not already infected with the proper bacteria, usually results in a marked increase in yield, it is also true that this "wonderful discovery" was made some fifteen years ago. It is not true that the mere inoculation of the soil "insures crops of alfalfa and other leguminous plants on all soils," as lime and phosphorus (and on some soils potassium) are just as essential as nitrogen-fixing bacteria. It is true that inoculation can be

produced by the use of such artificial cultures with sufficient care and proper manipulation, but it is also true that the surest and simplest method is to use natural soil, and usually this is the least expensive in the end, unless the infected soil must be shipped long distances. For further information relating to this subject, the reader is referred to Illinois Bulletin No. 76, "Alfalfa on Illinois Soils," and No. 94, "Nitrogen Bacteria and Legumes," and to Circular No. 86, "Science and Sense in the Inoculation of Legumes."

PHOSPHORUS.

It is true that we can increase the supply of nitrogen (the element needed least of all) by the use of legumes; and possibly, by means of decaying organic matter, by tile drainage, or by subsoiling, or by two or three of these methods, we can make available from the soil sufficient potassium for maximum profitable crop yields, and by feeding practically all of the crops and saving and returning to the soil all of the manure, we can perhaps maintain the supply of potassium indefinitely; *but there is no method known or suggested by which the ordinary soil of the Lower Illinois Glaciation can be made sufficiently rich in phosphorus to produce the most profitable crops without buying phosphorus in some form and applying it to the land.*

The average results of all experiments show that the increased crop yields produced by phosphorus are more than enough to pay for steamed bone meal sufficient to meet the needs of maximum crop yields, so that by proper use of steamed bone meal, the soil could be steadily enriched in phosphorus and yield an increased net profit at the same time. And it now seems evident that by proper use of large amounts of raw rock phosphate with decaying organic matter, the soil can be more rapidly enriched in phosphorus at less expense and with greater increase in net profits than with steamed bone meal.

The method of applying the rock phosphate may vary under different conditions. It may be sprinkled over the manure from day to day as it accumulates in the stable or feeding shed, at the rate of about 100 pounds of rock phosphate for each ton of manure; or it may be sprinkled over the manure as it is being loaded on the wagon or manure spreader; or it may be spread broadcast on the land and plowed under with stable manure or clover or cow peas, or other organic matter. If the ground could be disked before being plowed, and the phosphate and organic matter thus mixed with each other and with the soil, it would doubtless be an advantage.

There is no doubt that it is best to plow the phosphate under, but it is believed that the ground limestone which may be used on acid soils should not be plowed under, but rather applied after plowing and well mixed with the surface soil.

CROPS AND CROP ROTATIONS.

While any of the ordinary farm crops can be grown successfully on the soil of the Lower Illinois Glaciation, as shown by the fact that our best treated plots in 1904 produced higher yields than 60 bushels of corn, 40 bushels of oats, 30 bushels of wheat, and 2 tons of clover hay, nevertheless the soil is better adapted to some crops than to others. Undoubtedly wheat takes first rank among the crops well adapted to this soil and climate. The compact soil is very suitable for wheat culture. The fall weather is usually favorable to sowing wheat and the mild winter and early spring with abundant rainfall make almost ideal weather conditions for this crop. Furthermore, the wheat usually matures soon after the heavy spring rains and before the midsummer drouth. The nearness to the great wheat markets is an additional advantage.

The chief difficulties in wheat growing are the lack of proper plant food, the Hessian fly, the chinch bug, and the tendency of the farmer to grow wheat after wheat. By suitable rotation of crops, the development of the fly and chinch bugs is discouraged, and by rotation and proper treatment, the soil becomes able to produce strong growing plants which suffer less from insect attacks. Land bearing a heavy crop of wheat, especially with a good growth of clover in it, offers very unfavorable conditions for the chinch bug.

The oat crop is not well adapted to this soil and climate. Chiefly because the land is not well drained, the frequent early spring rains render it difficult to sow oats at the proper time, and the early summer drouth may injure the immature crop.

Unless the summer drouth is too severe, corn, cow peas, soy beans, and clover are very well adapted to this soil when properly treated.

The soil and climate are well adapted to the growing of timothy and redtop, but neither of these crops should be grown and sold from the farm as hay, except at very high prices, sufficient to cover the cost of the plant food removed and leave a profit.

The following rotations are suggested for consideration:

THREE-YEAR ROTATION.

First Year—Wheat, followed by cow peas or soy beans as catch crop.

Second Year—Corn, with cow peas or soy beans as catch crop.

Third Year—Cow peas or soy beans (to be followed by wheat).

Every three years, about 500 pounds of steamed bone meal should be applied for the wheat or 1,000 pounds of raw rock phosphate may be spread on the catch crop after wheat (preferably with farm manure) and plowed under for corn. As an initial application, 2 tons of ground limestone should be applied after the ground is plowed for corn, further applications to be applied as needed to keep the soil sweet, perhaps 1

ton every six years. All crops except the wheat should be fed or pastured or used as bedding and all manure returned to the land. If the corn crop is cut and shocked, then a three-year rotation of corn, wheat, and clover is a good one.

FOUR-YEAR ROTATION.

First Year—Corn, with cow peas or soy beans as catch crop.
Second Year—Cow peas or soy beans.
Third Year—Wheat (with clover to be seeded in spring).
Fourth Year—Clover.

If well filled the second crop of clover should be harvested for seed. All other crops excepting wheat and possibly cow pea or soy bean seed should be fed and the manure returned to the land, preferably mixed with about 1,500 pounds of rock phosphate and applied to the clover sod to be plowed under for corn.

FIVE-YEAR ROTATION.

This may be the same as the four-year rotation except that timothy may be seeded with clover and the land pastured the fifth year.

SIX-YEAR ROTATION.

This may be the same as above except that the land is pastured for two years. In this case some alsike should be seeded with the red clover and timothy, as the red clover is only a two-year plant (biennial) while alsike is a short perennial. About one ton per acre of ground rock phosphate should be applied with the manure to the pasture land to be plowed under for corn every six years, ground limestone to be applied after plowing as indicated above.

Whatever rotation is adopted, there should be as many fields (of approximately equal size) as there are years in the rotation, so that every crop can be grown every year. Where conditions will permit, we prefer the five-year or six-year rotation. It will be observed that a legume crop is provided for every year in every rotation suggested. If the cow peas or soy beans are cultivated and kept clean, the wheat may be seeded on the ground without plowing, in which case, the land is plowed only twice in four, five, or six years.

While cow pea seed and soy bean seed are valuable to sell for seed, they also have a very high feeding value, being very rich in protein and well suited to balance the carbohydrates in corn. As a rule the soil should be inoculated for soy beans. (See Bulletin No. 94.)

The comparative value of clover can be easily understood from the simple fact that when we were seeding cow peas and soy beans for the 1904 crop, we were at the same time cutting two tons per acre of red

clover hay as the first crop for 1904. It is not advised to discard the cow pea and soy bean, but it is advised to include clover to some extent at least in the crop rotation for the Lower Illinois Glaciation; not only because it grows from early spring till late autumn, and lives two years from one seeding, but because it roots deeply, markedly increases the power of the soil to absorb and retain moisture, obtains and liberates plant food present in the soil or subsoil or supplied in low grade materials, gathers nitrogen from the air, and leaves in the soil a large amount of roots rich in plant food elements.

NOTES.—Ground limestone can be obtained from the Crystal Carbonate Lime Company, Elsberry, Mo., or from the Mitchell Lime Company, Mitchell, Ind., for about $2.50 a ton, delivered in Illinois in carload lots, on direct east and west lines running into East St. Louis; on north and south lines it may cost 20 to 30 cents more. Illinois has abundance of good limestone, especially along the Mississippi and in the Ozark hills in the southern part of the state, and it is hoped that grinding plants will soon be established in Illinois so that ground limestone can be obtained more cheaply. It ought to be furnished at any point delivered in carload lots at a total cost of $2.00 a ton or less.

Finely ground raw rock phosphate (12½ percent phosphorus) can be obtained from Robin Jones, Nashville, Tenn., or from the N. Y. & St. L. Mining & Mfg. Co., St. Louis, Mo., for about $8.00 a ton delivered in southern Illinois in carload lots.

A good grade of steamed bone meal (about 12½ percent phosphorus) can be obtained delivered in southern Illinois for about $25.00 a ton, from the local agents of Armour & Company, Morris & Company, Swift & Company, or others, of the Union Stock Yards, Chicago, Ill., and potassium chlorid (42 percent potassium) can also be obtained from Armour & Company, for about $50.00 a ton, f. o. b. cars Chicago.

The Experiment Station does not analyze miscellaneous samples of soil or other materials for private parties. For methods employed in the investigation of Illinois soils, see Circular No. 68, or Bulletin No. 93, pages 302-3.